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High-Resolution NMR Probe Head for small Sample Volumes and Method of Op-
erating Same

Field of Application

The present invention relates to a probe head for NMR measurements, consisting of a support body carrying a solenoid coil via which a sample material can
5 be introduced into a measuring volume surrounded by the solenoid coil. The invention moreover relates to a method of operating such a probe head.

In NMR spectroscopy, a sample in a strong static basic magnet field B_0 is subjected to high-frequency pulses of an HF magnetic field oriented orthogonally
10 on the basic magnetic field and the HF pulses then emitted by the sample as measured and analysed. For the creation of basic magnetic fields as strong and homogeneous as possible, nowadays superconducting magnetic systems are frequently used. These magnetic systems are vertically arranged, as a rule, and present a central bore into which the exciting HF emitting and receiving coil with the
15 sample is introduced. The sample is located in the measuring volume surrounded by the emitting or receiving coil, respectively. The system constituted by the sample holder, the emitting and receiving coil as well as by the corresponding electrical leads, which are disposed on or in a support body, is referred to as probe head. This probe head with the sample holder and the emitting or receiving coil,
20 respectively, present an elongate shape adapted to the bore in the superconducting solenoid in many NMR systems. Prior to measurement, the probe head is removed from the solenoid bore, then a sample tube charged with the sample material is inserted into the sample holder, whereupon the probe head is pushed again into the bore of the solenoid. The sample tubes normally project beyond the

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measuring volume on both sides so that always a quantity of sample material is required that exceeds the quantity actually measured.

The German Patent DE 41 01 473 A1 discloses a probe head for liquid NMR spectroscopy, which permits an automated serial measurement of several samples. In the proposed probe head, a sample tube is clamped, which is open on both sides and which is connected to feed lines for the inflow and outflow of the liquid sample into the probe head. Due to these feed lines it is possible to supply intermittently defined volumes of a sample liquid in the so-called stop-flow technique. A continuous operation of the probe head is equally possible according to that prior art document. Due to an appropriate clamping device for the sample tube it is possible to replace the tube very rapidly so that the probe head can be operated with sample tubes having different wall thicknesses or different inside volumes, without the need to replace the probe head completely.

One disadvantage of this probe head consists, however, in the application of a saddle measuring coil as HF emitting and receiving coil because such a coil creates a homogeneous HF field only over one part of the volume surrounded by the coil. A very good HF homogeneity is, however, required specifically for the analysis of dissolved substances. A replacement of the sample tube may, moreover, result in the fact that the charging factor of the measuring coil with the new sample tube is not or no longer at an optimum. Another disadvantage of that known probe head consists in the aspect that here, too, sample quantities must be introduced which exceed the quantities that would be required for the measurement proper. When different sample materials are measured it is furthermore necessary to flush the feed lines in order to avoid intermixing of different samples.

The German Patent DE 42 34 544 C2 discloses a sample-changing system for liquid NMR spectroscopy, wherein a solenoid coil is proposed, too, as emitting and receiving coil, with the axis of the coil and of the sample tube being disposed orthogonally on the bore of the superconducting base field solenoid in the probe head. In the probe head of that device, the sample tube is equally connected to appropriate feed lines for the inflow and outflow of the liquid sample material so

that measurement can be carried out in the stop-flow mode or with a continuous flow. In view of the minimum sample volume and the measurement of different samples with this probe head, too, the same problems occur as those mentioned in relation to the afore-discussed prior art reference. In that system, the entire
5 probe head must be exchanged for the measurement of samples requiring a different inside diameter of the sample tube. An automated measurement of solid samples is not possible with these two probe heads.

Starting out from that prior art, one problem underlying the present invention
10 consists in providing a probe head as well as a method of operating the probe head, which permit the automated serial measurements of different samples in a simple manner, even with very small sample volumes. Moreover, the probe head should also permit the automated measurement of solid samples and, according to a particular embodiment, a simple optimisation of the charging factor with different
15 sample volumes.

Description of the Invention

This problem is solved by the probe head as well as by the method according to Patent Claim 1 or 12, respectively. Expedient embodiments of the probe head
20 and of the method can be derived from the description given below and from the embodiments.

In a manner known per se, the present probe head consists of a support body carrying a solenoid coil as measuring coil and of a feed line leading to the
25 solenoid coil, via which a sample material can be introduced into a measuring volume surrounded by the solenoid coil. The support body may have an elongate configuration, for instance, in which case the coil axis of the solenoid coil is preferably oriented orthogonally on the longitudinal axis of the support body. In the present probe head, the feed line leading to the solenoid coil is configured for re-
30 ceiving and conveying sample containers. It must therefore present a sufficient inside diameter for receiving the sample containers. Such a feed line may have a tubular configuration, for instance, is passed through the solenoid coil and consists

of an NMR material at least inside the solenoid coil. The sample to be measured is then charged into a suitable sample container, is conveyed in the feed line up to the measuring volume, is measured there and is then conveyed out of the measuring volume again. The sample containers may be so selected that they receive
5 only the minimum sample quantity that is required for the measurement. The diameter of the sample container is adapted to the inside diameter of the feed line in order to allow for unproblematic conveyance inside the feed line.

Due to this configuration of the probe head, an automated serial measurement
10 of any sample materials whatsoever is possible in a simple manner. For instance, the sample containers may be charged with liquid, solid and also gaseous sample materials and these samples can be measured in an automated manner. The use of sample containers short along the supply direction permits also the measurement of very small sample volumes.

15 The solenoid coil is preferably detachably connected to the support body so that it is easy to exchange in a simple manner at any time. Due to this detachable connection of the solenoid coil to the support body of the probe head, it is possible to hold a plurality of solenoid coils of different diameters available and to insert
20 them into the probe head in the case of need. On account of the simple exchangeability, the measuring volume can be adapted easily to the respective sample volumes to be measured so that the charging factor is at an optimum and hence a very good signal-to-noise ratio will be achieved. The application of solenoid coils instead of frequently used Helmholtz-type coils or saddle coils moreover
25 entails the advantage that the HF homogeneity is excellent throughout the sample volume in the solenoid coil. Solenoid coils are furthermore simple to produce at acceptable costs. According to the preferred embodiment of the present probe head, the connection between the solenoid coils and the support body is realised in the form of a plug-and-socket connector so that the coil can be exchanged
30 merely by removal of one coil and plugging of the respectively envisaged other coil. The plug-and-socket connectors provide preferably the electrical contacts

between the HF lines and the coil at the same time. The detachable connection may, of course, also be realised in another form, e.g. in the form of a clamp joint.

5 The feed line is preferably connected to an appropriate conveying mechanism that permits the transport of the sample containers in steps in the feed line. To this end, for instance, a plurality of sample containers may be introduced in succession into an appropriate collecting zone of the feed line prior to a measurement. This succession of sample containers is then conveyed in steps by means of the conveying mechanism in such a way that one of the sample containers is in
10 the measuring volume at each step and can be measured there. In the next step, the respective sample container already measured is conveyed out of the measuring volume whilst the next sample container is introduced by the conveying movement into the measuring volume.

15 Various techniques come into question for the conveying mechanism. For instance, the sample containers may be conveyed by means of air or another suitable propelling agent in the feed line. A mechanical slide displacing the sample containers in the feed line is equally appropriate.

20 Due to this configuration of the present probe head it is possible to perform an automated measurement of many samples, in particular also of solid samples, within the scope of the routine operation in a large-scale laboratory. With a suitable selection of the size of the sample containers it is also possible to measure even very small sample volumes that are preferably adapted to the size of the
25 measuring volume, which reduces hence the costs of the sample material. As small sample containers are used, which may be introduced in succession into the feed line, it becomes expediently possible to measure different samples with rapid changes, without the necessity to make provisions for laborious and expensive flushing of the feed lines to this end.

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Brief description of the drawings

The present invention will be briefly described again in the following by an embodiment with reference to the drawings, without any limitation of the general inventive idea. In the drawing:

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Fig. 1 is a fundamental illustration of the application of an NMR probe head in a superconducting base field solenoid;

Fig. 2 illustrates a partial view of an example of the configuration of the probe head in accordance with the present invention; and

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Fig. 3 shows one example of the extension of the feeders in the probe head according to the present invention.

Ways of realising the invention

Fig. 1 is an exemplary view of a typical arrangement for NMR spectroscopy with a superconducting base field solenoid 1. This superconducting base field solenoid 1 is vertically disposed in a Dewar vessel 2 and presents a central bore 3 for the introduction of the sample to be measured. A very homogeneous static magnetic field B_0 prevails in this bore 3, whose orientation is roughly indicated in the figure. For measuring, a sample is supplied to a probe head 4 that is introduced into the bore of the base field solenoid 1. This is schematically roughly indicated by the double arrow in Fig. 1. The probe head 4 comprises appropriate connectors 5 for the HF supply of the integrated emitting and receiving coil or for conveying the received signals on its end projecting from the base field solenoid 1. Such a probe head 4 includes normally an adapter circuit for adaptation of the probe head to the usual input resistance of 50Ω at the input of the probe head, and includes also a waveguide resonator that is matched to the emission frequency. This component is not the subject matter of the present invention and is therefore not shown explicitly in the present embodiment. They may be configured in the same manner as in other known probe heads in a manner known to those skilled in the art.

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Fig. 2 shows an example of a configuration of the inventive probe head at a scale of approximately 1 : 1, with this figure illustrating only the front zone of the probe head 4. The support body 6 of the probe head 4, onto which a solenoid coil is plugged, can be recognised in this front zone located in the centre of the bore 3 of the superconducting base field solenoid during the measuring cycle. The plug-and-socket connector 8 is roughly indicated merely schematically in this figure. The measuring volume 9 enclosed by the solenoid coil 7 is determined by the diameter of the coil 7 as well as by the coil's longitudinal extension. A set of several solenoid coils 7 of different lengths and diameters can be held available for varying the dimensions of this measuring volume 9, which coils can be plugged onto the support body 6 in the same manner. The solenoid coil 7 on the probe head 4 can be simply exchanged in this manner on the probe head 4 and may be matched to the respective dimensions of the sample volumes in order to achieve an optimum charging factor.

The sample materials are charged into sample containers 10 consisting, in the present example, of short small tubes of a material not interfering with the NMR measurement, which can be closed in a water-tight and air-tight manner by means of a plug made of Teflon, for instance. In the present example, a tube 12 of appropriate diameter is passed through the solenoid coil for conveying these sample containers 10, in which tube the sample containers 10 can be conveyed. This configuration permits the introduction of a great number of sample containers 10 with different samples into the tube and the conveyance of the sample container 10 out of the solenoid coil 7 by means of an air flow after each measurement of a specific sample, i.e. a sample in one of the sample containers 10, as well as the introduction of the next sample in the respective sample container 10. It is also possible to use a liquid as conveying agent, for instance in an approach to achieve the matching of susceptibility in the measuring volume 9.

Compared against conventional sample exchangers, wherein individual small NMR tubes are vertically introduced into the NMR probe head, this possibility of automatic sample change incurs substantially lower costs and is sturdier. In par-

5 ticular, several sample containers 10 with different samples can be introduced into an appropriate collector section 14 of the tube 12 with the present configuration of the probe head or the present method, respectively, from which collector section the sample containers 10 are then conveyed in steps through the measuring volume 9.

10 Fig. 3 illustrates an example of the extension of the tube 12 of the probe head 4, with the solenoid coil 7 being roughly indicated at the front end of the probe head 4. The tube 12 is connected to a conveyor device 13 that conveys the sample containers 10, which are initially introduced in succession in a collector section 14 between the conveyor device 13 and the probe head 4, for measurement through the measuring volume of the probe head 4. The probe head 4 need not be taken out of the bore 3 of the superconducting base field solenoid 1 to this end. The samples already measured are output into an appropriate collector station at the other end of the tube 12.

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List of Reference Numerals

1	superconducting base field solenoid
2	Dewar vessel
3	bore in the base field solenoid
4	probe head
5	connectors of the probe head
6	support body
7	solenoid coil
8	plug-and-socket connector
9	measuring volume
10	sample containers
11	plug
12	tube
13	conveyor device
14	collector section
15	collector station

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